

Physical Features

Long-Term Impact of Rising Sea Level and Major Hurricanes on Galveston Bay

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There is mounting evidence that the rise in global sea level during the past 12,000 years has been episodic in nature and punctuated by rises on the order of three to five cm/year (Anderson and Thomas, *in press*). Global warming could trigger similar events within the next several centuries if continued warming results in mass wasting of the West Antarctic Ice Sheet (Anderson and Thomas, *in press*).

An ongoing marine geological study by Rice University and the University of Houston focuses on the manner in which rising sea level has influenced Galveston Bay, with emphasis on the impact of rapid sea level rises. A second objective is to measure the long-term impact that major hurricanes have had on the bay. Toward these goals, we have acquired a grid of high resolution (uniboom) seismic reflection profiles and sediment cores from throughout the bay. These data, in conjunction with results from earlier studies, provide a record of bay evolution.

Galveston Bay is located within an incised fluvial channel that was initially carved during an earlier Pleistocene lowstand, tentatively assigned to Oxygen Isotope Stage 5 (about 100,000 years ago). Initial flooding of the bay during the more recent Holocene sea level rise occurred approximately 8000 B.P. At that time, the bay existed within the deep, narrow portion of the valley. The broad, shallow platform of the bay flooded approximately 4000 years ago, perhaps during a rapid sea level rise, creating the present bay setting. Sediment cores that penetrate beyond, or just beneath, the Holocene bay-fill lack transitional (fining upwards) deposits, implying rapid flooding. Ongoing analyses are concentrating on understanding the development of the salinity structure within the bay and on measuring changes in bay fauna since 4000 B.P. Changes in salinity are measured using oxygen and carbon isotopes.

Several major storms have impacted the Galveston Bay complex during the past 4000 years. Some of these storms impacted the coast and bay far more than have storms of the past century (i.e., Hurricane Alicia). Yet, these storms had only a minor impact on the upper reaches of the bay. In fact, they left little in the way of a sedimentary record.

During 1991 field season we expect to acquire additional sediment cores from the bay along a transect extending from the deeper portions of the valley to the shoreline. We will attempt to measure the rate of sea level rise over the past 8000 years using radiometric dates from samples just above the flooding surface. We also will gather 3.5 Khz subbottom profiles from the bay to study changes in sedimentation within the bay over century-scale to decadal-scale time periods. Of

particular interest is the manner in which man has altered the sedimentation regime of the bay.

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Historical Shoreline Changes in the Galveston Bay System

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Shorelines of the Galveston Bay system, like those of most other Texas bays, have been eroding for several thousand years, causing the bays to widen and shoal. This natural phenomenon has become a concern as development has progressively increased around Galveston, Trinity, East, and West Bays, which form the Galveston Bay system. Natural bay shore erosion, augmented by human activities, threatens homes and industries as well as ecologically important plant and animal communities.

Roughly 232 mi of shoreline rims the Galveston Bay system. This shoreline can be divided into three principal types: steep bluffs composed chiefly of consolidated clay, low salt- and brackish-water marshes, and sand and shell beaches. Marshes are the most abundant shoreline type in the Galveston Bay system, making up 61% of the shoreline. Marshes are most common in East and West Bays. Steep bluffs coincide with the Pleistocene Beaumont formation and make up about 35% of the shoreline. These Pleistocene bluffs are five to 25 ft high and are the predominant shoreline type in Galveston and Trinity Bays. Sand and shell beaches compose only about four percent of the shoreline in the Galveston Bay system. They typically occur on the flanks of promontories or at the entrances to minor embayments where either wave energy is high or littoral currents converge.

Historical shoreline changes in the Galveston Bay system were documented by comparing shoreline positions for: (1) an early period between 1850-52 and 1930, when human activities had less effect than they do today; (2) a later period between 1930 and 1982, when human activities affected the bay system in many ways; and (3) the combined period between the 1850s and 1982, to establish long-term shoreline trends (Paine and Morton, 1986). Shoreline positions were those depicted on topographic charts made in the early 1850s and aerial photographs taken in 1930 and 1982.

Comparisons of past shoreline positions reveal that 78% of the shoreline in the Galveston Bay system underwent erosion between the 1850s and 1982. Average net rates of retreat were 2.2 ft/yr, which translates to a net land loss around the bay perimeter of 8,000 acres. Rates of net retreat were higher during the most recent period, increasing from 1.8 ft/yr before 1930 to 2.4 ft/yr after 1930. The shoreline between Cedar Bayou and Virginia Point eroded at an average rate of 3.0 ft/yr, the highest rate observed for any segment of the bay system. The only area of extensive shoreline progradation was the southern part of the Trinity delta, which advanced at 14 to 43 ft/yr.

Considering only the eroding shorelines, the average rate of retreat in the Galveston Bay system was 3.9 ft/yr between 1930 and 1982. This rate falls in the middle of the range of erosion rates observed in other major Texas bays (Morton and Paine, 1990). This rate, when combined with the length of retreating

shoreline, results in an estimate of 70 acres/yr of land loss in the Galveston Bay system. The most rapid erosion, 6.1 ft/yr, occurred along sand and shell beaches. Because this shoreline type is uncommon, erosion along sand and shell beaches contributed only 5.7 acres/yr to the land-loss total. Marshes eroded at a rate of 4.1 ft/yr on average, but their abundance makes them the largest land-loss component at 46.5 acres/yr. Bluffs retreated at the lowest rate of the major shoreline types, 3.2 ft/yr, and added 18.9 acres/yr to the land-loss total.

Both natural and human-induced factors contributed to the observed shoreline erosion in the Galveston Bay system. Natural causes of shoreline erosion include wave activity, storms, relative sea-level rise, and bluff failure. Wave activity, in order of increasing severity and decreasing incidence, is caused by the predominant southeasterly winds, strong northerly winds accompanying the passage of polar fronts, and extreme winds associated with tropical cyclones. Shorelines with long northerly and southeasterly wave fetches commonly have the highest rates of shoreline erosion. Tropical cyclones, in addition to producing destructive waves, raise bay water levels enough to cause waves to break on the middle and upper parts of the bluffs.

Since 1850, 15 hurricanes with surge heights of six feet or higher have struck the Galveston Bay area. Extreme examples include the 1900 storm, which had tides of 20 ft at Galveston (Sugg and *et al.*, 1971); the 1915 storm, which had a surge of 16 ft at the Galveston Causeway (Sugg *et al.*, 1971); Hurricane Carla, which elevated water levels to 15 ft in upper Galveston Bay (U.S. Army Corps of Engineers, 1962); and most recently Hurricane Alicia, which had a storm surge of 11 ft at LaPorte (U.S. Army Corps of Engineers, 1983). During Hurricane Alicia, bluff retreat typically ranged from 5 to 20 ft. Retreat of as much as 100 ft occurred along western Trinity Bay, where bluffs were exposed to the energetic right-front storm quadrant. Relative sea-level rise, including both "eustatic" sea level rise and land subsidence, is another natural cause of shoreline erosion. Because historical rates of sea-level rise are in the 0.1 to 0.5 inch/yr range, they have little impact on bluffs but can severely affect marshes.

The increase in erosion rates through time is a clear indication that human activities have augmented natural erosional processes. In the Galveston Bay system, wave energy has been increased by ship and boat traffic and by dredging and deepening parts of the bay system. Relative sea-level rise has been enhanced by subsidence related to hydrocarbon production (Pratt and Johnson, 1926) and ground-water withdrawal (Gabrysch, 1984) and possibly by increasing rates of sea-level rise through global warming. Many coastal structures such as riprap, bulkheads, and groins have slowed erosion locally but contribute to bay-wide erosion by removing sediment from the littoral system. Sediment transported to the bay system by rivers allows marshes to counter subsidence and sea-level rise, but reductions in the suspended sediment load carried by rivers as a result of reservoir construction and flood control have undoubtedly contributed to the acceleration of marsh erosion rates observed after 1930.

In summary, shorelines of the Galveston Bay system have eroded naturally for thousands of years. Recent human activities, such as production of ground water and hydrocarbons, construction of bulkheads, groins, and other impediments to

littoral drift, ship and boat traffic, construction of dams and reservoirs, and the release of "greenhouse" gases into the atmosphere, have all contributed to the severity of the shoreline erosion problem.

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